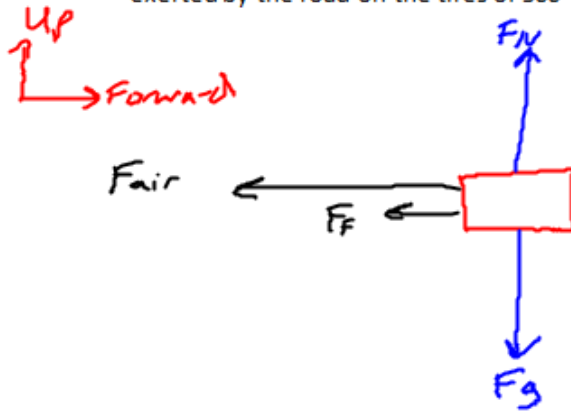
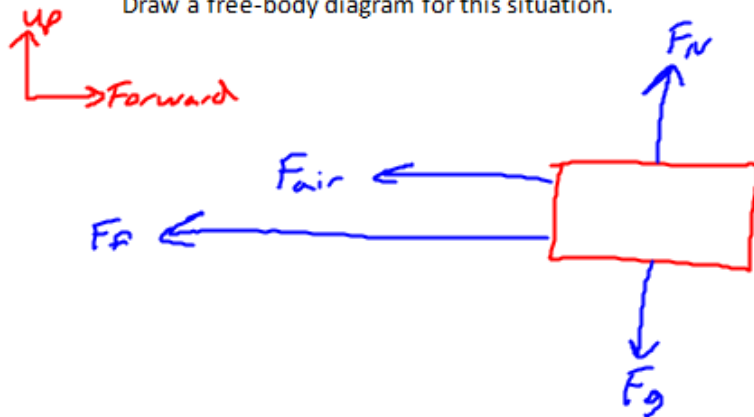


## Free-Body Diagrams

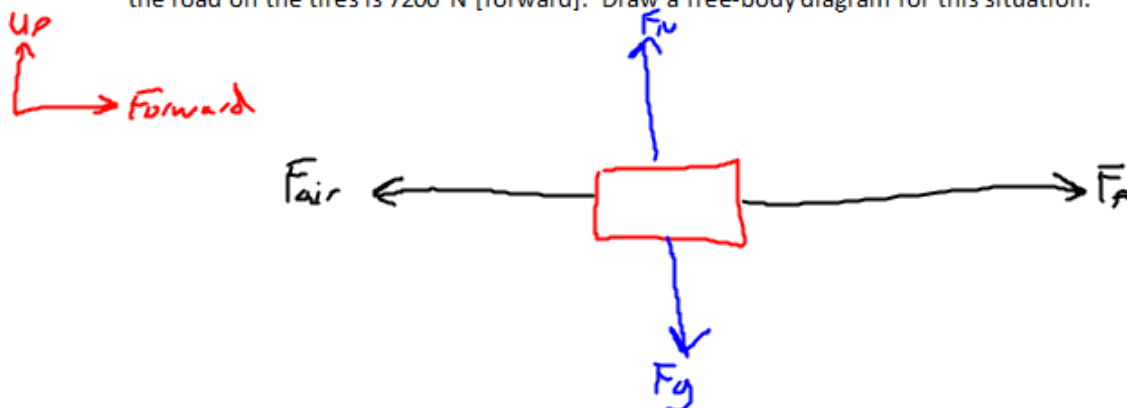
- 1) A car with a weight,  $F_g$ , of 10 000 N [down] is coasting on a level road. The car experiences a normal force,  $F_N$ , of 10 000 N [up], a force of air resistance,  $F_{air}$ , of 2500 N [backward], and a force of friction,  $F_f$ , exerted by the road on the tires of 500 N [backward]. Draw a free-body diagram for this situation.



- 2) The driver in Example 3.1 sees a pedestrian and steps on the brakes. The force of air resistance is 2500 N [backward]. With the brakes engaged, the force of friction exerted on the car is 5000 N [backward]. Draw a free-body diagram for this situation.



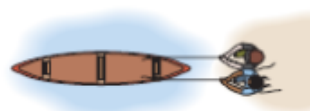
- 3) A car moving at constant velocity starts to speed up. The weight of the car is 12 000 N [down]. The force of air resistance is 3600 N [backward]. With the engine engaged, the force of friction exerted by the road on the tires is 7200 N [forward]. Draw a free-body diagram for this situation.



## Net force:

- 1) Two people, A and B, are dragging a canoe out of a lake onto a beach using light ropes. Each person applies a force of 60.0 N [forward] on the rope. The force of friction exerted by the beach on the canoe is 85.0 N [backward]. Starting with a free-body diagram, calculate the net force on the canoe. [35.0 N [forward]]

backward ← forward



→ Forward

$$\begin{array}{l}
 \vec{F}_f \leftarrow \\
 \vec{F}_{A1} \rightarrow \\
 \vec{F}_{A2} \rightarrow \\
 \vec{F}_f \leftarrow
 \end{array}$$

$$\begin{aligned}
 F_{A1} &= 60.0\text{ N} \\
 F_{A2} &= 60.0\text{ N} \\
 F_f &= -85.0\text{ N} \\
 \vec{F}_{\text{net}} &= \vec{F}_{A1} + \vec{F}_{A2} + \vec{F}_f \\
 \vec{F}_{\text{net}} &= 60.0\text{ N} + 60.0\text{ N} + (-85.0\text{ N}) \\
 \vec{F}_{\text{net}} &= 35.0\text{ N [forward]}
 \end{aligned}$$

- 2) Two dogs, A and B, are pulling a sled across a horizontal, snowy surface. Dog A exerts a force of 200 N [forward] and dog B a force of 150 N [forward]. The force of friction exerted by the snow on the sled is 60 N [backward]. The driver attempts to slow down the sled by pulling on it with a force of 100 N [backward]. Starting with a free-body diagram, calculate the net force on the sled. [190 N [forward]]

→ Forward

$$\begin{array}{l}
 \vec{F}_p \leftarrow \\
 \vec{F}_f \leftarrow \\
 \vec{F}_{Aa} \rightarrow \\
 \vec{F}_{Ab} \rightarrow
 \end{array}$$

$$\begin{aligned}
 F_{Aa} &= 200\text{ N} \\
 F_{Ab} &= 150\text{ N} \\
 F_f &= -60\text{ N} \\
 F_p &= -100\text{ N} \\
 \vec{F}_{\text{net}} &= \vec{F}_{Aa} + \vec{F}_{Ab} + \vec{F}_f + \vec{F}_p \\
 \vec{F}_{\text{net}} &= 200\text{ N} + 150\text{ N} + (-60\text{ N}) + (-100\text{ N}) \\
 \vec{F}_{\text{net}} &= 190\text{ N}
 \end{aligned}$$

- 3) In a tractor pull, four tractors are connected by strong chains to a heavy load. The load is initially at rest. Tractors A and B pull with forces of 5000 N [E] and 4000 N [E] respectively. Tractors C and D pull with forces of 4500 N [W] and 3500 N [W] respectively. The magnitude of the force of friction exerted by the ground on the load is 1000 N.

N  
↑  
→ E

$$\begin{array}{l}
 \vec{F}_c \leftarrow \\
 \vec{F}_d \leftarrow \\
 \vec{F}_f \leftarrow \\
 \vec{F}_a \rightarrow \\
 \vec{F}_b \rightarrow
 \end{array}$$

$$\begin{aligned}
 F_a &= 5000\text{ N} \\
 F_b &= 4000\text{ N} \\
 F_c &= -4500\text{ N} \\
 F_d &= -3500\text{ N} \\
 F_f &= -1000\text{ N}
 \end{aligned}$$

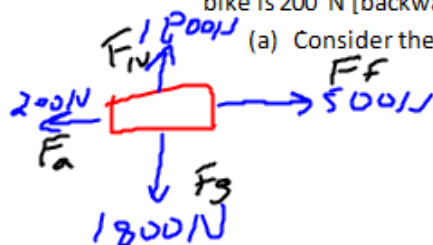
$$\begin{aligned}
 \vec{F}_{\text{net}} &= \vec{F}_a + \vec{F}_b + \vec{F}_c + \vec{F}_d + \vec{F}_f \\
 \vec{F}_{\text{net}} &= 5000\text{ N} + 4000\text{ N} + (-4500\text{ N}) + (-3500\text{ N}) + (-1000\text{ N}) \\
 \vec{F}_{\text{net}} &= 0\text{ N}
 \end{aligned}$$

- (b) If the load is initially at rest, will it start moving? Explain. [No]

No - net force is 0N!



- 4) The total weight of a biker and her motorbike is 1800 N [down]. With the engine engaged, the force of friction exerted by the road on the tires is 500 N [forward]. The air resistance acting on the biker and bike is 200 N [backward]. The normal force exerted by the road on the biker and bike is 1800 N [up].



- (a) Consider the biker and bike as a single object. Draw a free-body diagram for this object.

- (b) Calculate the net force. [300 N [forward]]

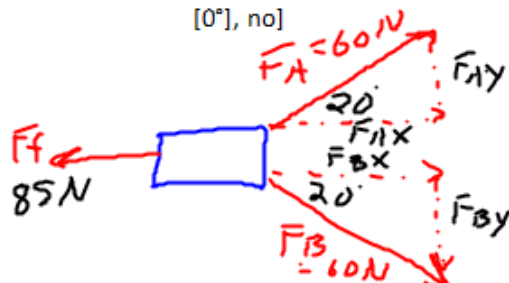
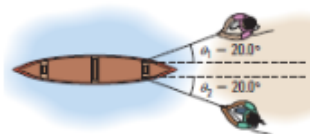
$$F_{netx} = F_f + F_a$$

$$F_{netx} = 500\text{ N} + (-200\text{ N})$$

$$F_{netx} = 300\text{ N}$$

$$F_{net} = 300\text{ N [forward]}$$

- 5) Refer to question one. Person A thinks that if A and B each pull a rope forming an angle of  $20.0^\circ$  with the bow, the net force on the canoe will be greater than in question one. The canoe is being dragged along the beach using ropes that are parallel to the surface of the beach. Starting with a free-body diagram, calculate the net force on the canoe. Is person A's thinking correct? [27.8 N  $[0^\circ]$ , no]



$$F_{Ax} = 60\text{ N}(\cos 20^\circ)$$

$$= 56.382\text{ N}$$

$$F_{Ay} = 60\text{ N}(\sin 20^\circ)$$

$$= 20.521\text{ N}$$

$$F_{Bx} = 60\text{ N}(\cos 20^\circ)$$

$$= 56.382\text{ N}$$

$$F_{By} = 60\text{ N}(\sin 20^\circ)$$

$$F_{By} = -20.521\text{ N}$$

$$F_{nety} = F_{Ay} + F_{By}$$

$$F_{nety} = 20.521\text{ N} + (-20.521\text{ N})$$

$$F_{nety} = 0\text{ N}$$

$$F_{netx} = F_{Ax} + F_{Bx} + F_f$$

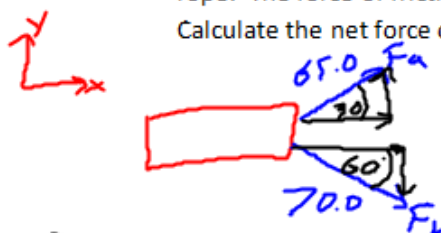
$$F_{netx} = 56.382\text{ N} + 56.382\text{ N} + (-85\text{ N})$$

$$F_{netx} = 27.764\text{ N}$$

$$F_{net} \approx 27.8\text{ N } [0^\circ]$$

- 6) Refer to question five. Suppose person A pulls a rope forming an angle of  $40.0^\circ$  with the bow and person B pulls a rope forming an angle of  $20.0^\circ$  with the bow. Each person applies a force of  $60.0\text{ N}$  on the rope. The canoe and ropes are parallel to the surface of the beach. If the canoe is being dragged across a horizontal, frictionless surface, calculate the net force on the canoe. [ $104\text{ N } [0^\circ]$ ]

- 7) Two people, A and B, are dragging a sled on a horizontal, icy surface with two light ropes. Person A applies a force of  $65.0\text{ N } [30.0^\circ]$  on one rope. Person B applies a force of  $70.0\text{ N } [300^\circ]$  on the other rope. The force of friction on the sled is negligible and the ropes are parallel to the icy surface. Calculate the net force on the sled. [ $95.5\text{ N } [343^\circ]$ ]



X

$$\vec{F}_{\text{net}} = \vec{F}_{\text{ax}} + \vec{F}_{\text{bx}}$$

$$\vec{F}_{\text{net}} = 56.292\text{ N} + 35.0\text{ N}$$

$$F_{\text{net}} = 91.292\text{ N}$$

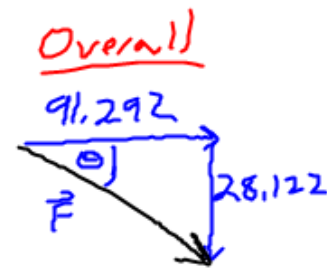
Y

$$\vec{F}_{\text{net}} = \vec{F}_{\text{ay}} + \vec{F}_{\text{by}}$$

$$\vec{F}_{\text{net}} = 32.5\text{ N} + (-60.622\text{ N})$$

$$\vec{F}_{\text{net}} = -28.122\text{ N}$$

Overall



$$F_{\text{net}} = \sqrt{(91.292)^2 + (28.122)^2}$$

$$F_{\text{net}} \approx 95.5\text{ N}$$

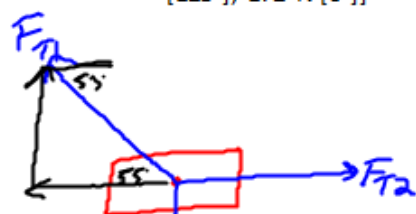
$$\theta = \arctan\left(\frac{28.122}{91.292}\right)$$

$$\theta \approx 17^\circ$$

$\therefore \vec{F}_{\text{net}} = 95.5\text{ N } [E 17^\circ S]$   
 or  $[95.5\text{ N } [343^\circ]]$

$\vec{F}_{\text{ax}} = 65.0 \cos 30^\circ = 56.292\text{ N}$   
 $\vec{F}_{\text{ay}} = 65.0 \sin 30^\circ = 32.5\text{ N}$   
 $\vec{F}_{\text{bx}} = 70.0 \cos 60^\circ = 35.0\text{ N}$   
 $\vec{F}_{\text{by}} = -70.0 \sin 60^\circ = -60.622\text{ N}$

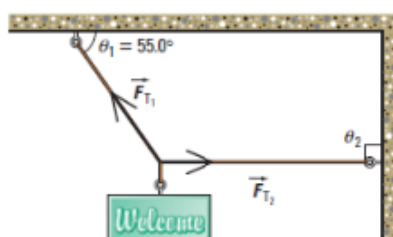
- 8) A store sign that experiences a downward gravitational force of 245 N is suspended as shown in Figure 3.18. Calculate the forces  $F_{T1}$  and  $F_{T2}$  exerted at the point at which the sign is suspended. [299 N [125°], 172 N [0°]]



$F_g = 245 \text{ N}$   
 Sign is not accelerating  
 $\therefore F_{\text{NET}} = 0$

$$F_{T1y} = F_{T1} \sin 55^\circ$$

$$F_{T1x} = -F_{T1} \cos 55^\circ$$



Vertical

$$F_{\text{NET}y} = F_{T1y} + F_g$$

$$F_{T1y} = -F_g$$

$$F_{T1y} = -(-245 \text{ N})$$

$$F_{T1y} = 245 \text{ N}$$

$$F_{T1y} = F_{T1} \sin 55^\circ$$

$$\frac{F_{T1y}}{\sin 55^\circ} = F_{T1}$$

$$\frac{245 \text{ N}}{\sin 55^\circ} = F_{T1}$$

$$299.0897742 \text{ N} = F_{T1}$$

Horizontal

$$F_{\text{NET}x} = F_{T1x} + F_{T2}$$

$$-F_{T1x} = F_{T2}$$

$$-(299.0897742 \cos 55^\circ) = F_{T2}$$

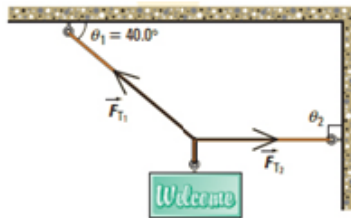
$$171.5508489 \text{ N} = F_{T2}$$

$$F_{T1} = 299 \text{ N} [125^\circ]$$

$$F_{T2} = 172 \text{ N} [0^\circ]$$

- 9) If the sign question eight had half the weight, how would the forces  $F_{T1}$  and  $F_{T2}$  compare? [directions of  $F_{T1}$  and  $F_{T2}$  would remain the same as before, but the respective magnitudes would be half]

- 10) Suppose the sign in question eight is suspended as shown in the picture below. Calculate the forces  $F_{T1}$  and  $F_{T2}$ . [381 N [140°], 292 N [0°]]



- 11) Refer to questions eight and ten above.

a. As  $\theta_1$  decreases, what happens to  $F_{T1}$  and  $F_{T2}$ ? [ $F_{T1}$  and  $F_{T2}$  increase in value]

b. Explain why  $\theta_1$  can never equal zero. [magnitude of  $F_{T1}$  must always equal  $F_g$ ]

- 12) A sign that experiences a downward gravitational force of 245 N is suspended, as shown below. Calculate the forces  $F_{T1}$  and  $F_{T2}$ . [ $1.50 \times 10^2$  N [ $125^\circ$ ],  $1.50 \times 10^2$  N [ $55^\circ$ ]]

